Board 56: Assessing Interest and Appeal of Engineering in a High School Program Designed to Enhance Entry into Engineering in an INCLUDES project

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Introduction

It is well-established that science, technology, engineering, and mathematics (STEM) fields lack diversity, evidenced by poor distribution of gender and socioeconomic status [1]. Interestingly, research suggests this homogeneity is most pronounced in engineering undergraduate and graduate programs [1]. For example, the National Science Foundation has reported that women's involvement in engineering academic programs and professions has decreased, or has increased at disproportionately slow rates, since 1990 [2]. Furthermore, of the nearly 2 million students who completed the American College Test (ACT) in 2006, just one percent of women expressed a measured interest in engineering [1]. Social cognitive theories addressing the gender gap in STEM, and specifically in engineering, have been examined in recent research. Data suggest women and low-income students are least likely to matriculate with engineering degrees [3], suggesting these populations may demonstrate decreased self-efficacy. Self-efficacy beliefs are significant predictors of academic success, where STEM-specific self-efficacy beliefs relate to entry and retention in STEM majors [4]. Moreover, it has been found that women and minority students are less likely to report interest in STEM fields [4]. These findings are important, because students who express measured interest in STEM are more likely to major in science and engineering, and are more likely to persist in those majors [1].

The purpose of the current study is to examine the engineering interests held by a diverse sample of high school students, along with a battery of social cognitive factors related to interest – including experience with engineering, knowledge and understanding of engineering as a career field, and identity as an engineer. The study is part of an overarching program of research at Arizona State University's Ira A. Fulton Schools of Engineering, aimed at testing the efficacy of an out-of-school engineering program, *Young Engineers Shape the World* embedded in an NSF sponsored project. This project, *Engineers from Day One*, aims to facilitate the engineering identities of female, first-generation, and underrepresented minority students, with the goal of increasing these students' entry and retention in engineering majors. The project is funded by a National Science Foundation *Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science* (NSF INCLUDES) grant [5]. Our motivation stems from and is aligned to ASU's New American University design principles [6] of a comprehensive public research university serving 109,500 students that is measured not by whom we exclude, but rather by whom we include and how they succeed. ASU's mission is to: 1) provide access to all students qualified to study at a research university; 2) maintain access to match Arizona's socioeconomic diversity.

Because data were collected as part of an overarching program of research studying the efficacy of pre-college engineering programs, outcomes of interest include increased entry into an engineering major; increased retention after the first year of declaring an engineering major; and increased persistence to graduation from an engineering program. Ultimately, this program of research aims to diversify the student population graduating from engineering at Arizona State University, one of the largest public research universities, by enrollment, in the United States. Attracting and retaining more female, first-generation, and underrepresented minority students, including those with socioeconomic need, in the engineering workforce will augment innovation, creativity, and global competitiveness. A diversified workforce will result in improved scientific and technological products, services, and solutions that will be better designed for and representative of all users [7, 8]. Fostering diversity-driven creativity requires a diverse group of students to enter, retain, and persist in engineering degree pathways [9, 10]. Further, our program of research recognizes that meeting these goals, and at scale, will require a collective effort [11, 12] from a broad group of social institutions uniting around a common agenda [13]. Here, the common agenda is to enhance entry, retention [14], and persistence in engineering [4] to ultimately yield a diverse population of engineers.

Lack of adequate financing and a paucity of knowledge about potential revenue streams to support college completion negatively impact the entry of female, first-generation, and underrepresented minority students into four-year universities [15,16]. Moreover, in the United States first-generation status and ethnic minority membership are highly confounded with socioeconomic need. For many of these students, transition to a four-year university is affected by college preparation (i.e. courses taken in high school, academic success strategies such as notetaking), financial aid, and the college applications and admissions processes; these factors are in addition to students' development as successful engineering students [17]. Thus, a general framework to characterize the challenges in diversifying engineering can be summarized as: 1) lack of *awareness* about engineering and what engineers do; 2) absence of *enjoyment* or an affective response to engineering; 3) dearth of *interest* in engineering pathways and careers; 4) paucity of *opinion formation* about the impact of engineering on society; and 5) poor *understanding* of engineering and its social value.

To address this challenge, we developed a conceptual framework based on James Marcia's theory [18, 19] that identity development in youth is the degree to which one has explored and committed to a vocation. Achieving an engineering identity includes: *crisis*—i.e., a time when one's values and choices are being examined and reevaluated, and *commitment*—when the outcome of a crisis leads to a commitment made to becoming an engineer. To this end, through the *Young Engineers Shape the World* program, Arizona State University, offered engineering experiences during the crisis phase to influence values and choices and to facilitate commitment—choosing to become an engineering student. Identity development was fostered through: 1) targeted mentoring [20, 21] and with information on ways to fund college attendance; 2) experiences [22] that increase knowledge of engineering as socially impactful [21]; 3) experiences that reveal creativity, collaboration, and communication as essential in engineering. These mechanisms are instituted in the *Young Engineers Shape the World* program to vigorously challenge barriers to entry [23] at critical junctures, starting from one's identity and beliefs as to who can be an engineer to confronting stereotypes of engineers and their workplaces, to highlighting the value engineers add to society and their profession, and finally to demonstrating how engineers find personal satisfaction [24].

This paper presents findings from efforts to study the awareness, enjoyment, interest, opinion formation, and understanding that high school students have towards engineering. These high school students were enrolled in a year-round program, *Young Engineers Shape the World*. Further, this paper examines changes in high school students' awareness, enjoyment, interest, opinion formation, and understanding of engineering as a result of participation in an out-of-school pre-college engineering program. A questionnaire was administered to a sample of high school students (*N* = 334, 53.3% female, 60.6% non-white, 77.1% first-generation) via the online survey platform Qualtrics. In addition to collecting demographic information, the questionnaire collected data on students' experience with engineering, their understanding of who engineers are and what they do, and their identities as future engineers.

Method

The *Young Engineers Shape the World* program is facilitated by a program coordinator and implemented in four different geographic locations (three university campus locations and a high school district location) across a span of 50 miles. Additionally, 20 university students act as mentors to participants, by assisting the coordinator with program implementation and supervision of program activities. These mentors are selected from a pool of undergraduate engineering applicants with a passion for service learning and prior experience in an entrepreneurship program. They received extensive training by the program coordinator to serve as mentors and were paid a stipend of $300 per semester of mentorship.

Recruitment of participants occurred using a variety of strategies. To begin, the university's K-12 engineering education and outreach department sends monthly newsletters to parents, educators, industry partners, and K-12 students; this became an excellent dissemination and recruitment vehicle for the program. Staff also presented the program at regional K-12 events to spread awareness about the program and its potential impact. This department also hosted a STEM teachers conference at the university campus, whose mission was to serve the real-world needs of teachers to stimulate best teaching practices in STEM. Presentations and meetings were held with school district leaders, STEM academic coaches, and educators to help increase awareness about the engineering program and to recruit participants. Fliers were distributed to high schools in the pilot alliance and those located in areas surrounding the sites where the program was offered. Fliers were also distributed across the metropolitan area, including at libraries, coffee shops, and grocery stores. All fliers and program resources were available in both Spanish and English. Finally, open informational sessions were held for interested students and families. Spanish language translators were available at these sessions.

Following recruitment, students were encouraged to submit applications to the program. An online version of the application, as well as a paper application packet, were available. Eligible applicants were enrolled in 11th grade, had expressed interest in exploring engineering and learning more about engineering majors, and could commit to the two-year program by attending Saturday workshops and two mandatory evening sessions on financial aid and the college experience. All eligible students who applied were accepted to the program. Further, all applicants were given the option to participate in research; upon providing parental consent and student assent, these students were considered research participants.

At the start of the Fall semester, a Saturday kick-off event was held for families and students at the main university campus location. Participants completed a design challenge as a family group. It was important for students' families be involved in program activities, so we could draw upon the family's influence in their student's exploration of engineering education and career pathways, while also building trust. Following the kick-off event, Saturday workshops were offered throughout the academic year. Workshops were scheduled as three-hour sessions, rotating between mornings and afternoons, with each workshop ultimately offered at all four locations in one program year. Workshops were arranged thematically; topics included the following broad experiences that had an anchor in offering social and personal relevance in engineering for the participants:

- *Harness Wind Energy*
  Participants learned about energy generation, and the application of aerodynamic principles to capture the wind's energy most effectively. Participants designed wind turbine blades to attach to a model wind turbine to generate electricity.
- *Providing Access to Clean Water*
  Participants learned about chemical engineering and processes used to treat drinking water. Participants designed and tested water filtration devices.
- *Introduction to Programming Arduinos*
  Participants learned basic Arduino circuitry and coding to power LED lights and other simple projects from the Arduino Starter Kit booklet.
- *A Flood-Sensor Design Project*
  As continuation to the skills learned in the previous workshop, participants learned how engineers use microcontrollers and programming to develop emergency alert systems. This particular workshop focused on designing a flood sensor that could be used as a warning during times of heavy flooding.
- *Nano-Robots to Simulate targeting Cancer Cells*
  Participants used sensors and cancer cell models to learn about and design nano-robots that could destroy cancer cells. This activity focused on the future of biomedical engineering and targeted the impact of engineering on medicine/human health.
- *Harness Solar Energy*
  Participants worked in teams to develop solar powered cars. Participants learned about research conducted a solar energy based Engineering Research Center at brainstormed ways to implement solar energy into other products.
- *Human Centered Designed*
  Participants formed groups and identified solutions to meet a community need. Participants gained experience interviewing, designing, communicating designs, implementing feedback, and presenting final prototypes.
- *Bridge Design*
  Participants first gained knowledge into soil analysis through an activity developed an Engineering Research Center, and then determined which type of soil would form the strongest foundation for a bridge. Following soil analysis, students developed bridges that could hold a specific amount of weight.
- *Rocket Launching*
  Participants designed and prototyped bottle rockets with parachutes and launched them to observe their function. Through this activity, students gained insight into aerospace engineering and how rockets can be used for a variety of things, from delivering satellites into orbit to sending rovers to Mars.
- *Cybersecurity Encryption*

Cybersecurity is a key part of national and personal security. This activity showed participants key concepts in cybersecurity with a focus on encryption. Participants worked on cracking various ciphers, and then designed with an Arduino kit to program an encryption and decryption code based on the Caesar Cipher.

- *Robotics Hydraulic Arm Design*
  Participants designed and built a hydraulic robot arm with laser cut wood materials, surgical tubing, and syringes filled with water. They were presented with the various uses robotics has in industry, from healthcare to manufacturing to aerospace exploration.

In addition to Saturday workshops, participants were offered the following opportunities to engage in throughout the academic year:

- *Field trip to Arizona State University's Innovation Showcase*
  Participants attended the Innovation Showcase and took part in an activity focused on how to communicate research to various audiences. Participants worked in groups to gain skills on adapting communication methods depending on the age/education/experience of their various audiences. At the Innovation Showcase, participants interacted with graduating engineering seniors who demonstrated their capstone projects, many of which were industry sponsored.
- *An Evening with Undergraduate Engineering Students*
  Participants and their parents networked with undergraduate students to learn about the college going experience first-hand from those who are in college and are closest to the participants.
- *Opportunities to Build an Engineering Identity*
  Industry professionals from General Motors, Intel, and other major technology companies and university students who have held internships and conducted undergraduate research interacted with participants about the process of securing an internship and why they are an important component of building an engineering career.
- *An Evening with Industry Engineers*
  Participants and their parents had the opportunity to network with industry professionals. Engineers from five companies attend and shared their journeys into engineering, offered insights into their workday and the nature of their work thereby providing participants with knowledge about the engineering workplace.

Materials. A *What is Engineering* questionnaire was designed and implemented to elicit students' recognition of engineering problems as relevant to society *and* whether they find social and personal relevance in wanting to solve these problems. Modeled after a National Academy of Sciences [25, 26] study this questionnaire was administered with program participants at the start of the academic year. The *What is Engineering* questionnaire prompted participants to i) *Describe Engineering* and ii) *Describe Engineers*. The *What is Engineering* questionnaire included 8 items to describe engineering, where participants rated each item on a Likert-type scale ranging from 1 (very well), 2 (somewhat well), 3 (not very well), to 4 (not well at all). Low scores indicate high awareness, interest, enjoyment, opinion formation, and understanding of engineering as a potential career field. Further, the questionnaire included 21 items to describe engineers, where participants again rated each item on the Likert-type scale described above. Again, low scores indicate high awareness, interest, enjoyment, opinion formation, and understanding of engineers. Additionally, participants completed a measure of *Engineering Identity*. This measure was designed to elicit students' identities as future engineers. The *Engineering Identity* measure consisted of 15 items, where participants rated each item on a Likert-type scale ranging from 1 (strongly agree), 2 (agree), 3 (neutral), 4 (disagree), to 5 (strongly disagree). Low scores indicate high engineering identities. The *Engineering Identity* survey was designed by project leaders in consultation with a counseling psychologist who has extensive experience in studying how students make vocational education choices. This survey is based on James Marcia's theory [18, 19] that identity development in youth is the degree to which one has explored and committed to a vocation. Achieving an engineering identity includes: *crisis*—i.e., a time when one's values and choices are being examined and reevaluated, and *commitment*—when the outcome of a crisis leads to a commitment made to attending an institution of higher-education to become an engineer. To this end, the program offers engineering experiences during the crisis phase to influence values and choices and to facilitate commitment—choosing to become an engineering student by pursuing an engineering program.

Participants. A total of 334 high school students applied and were accepted to the program, and had provided parental consent and student assent to participate in research. Of this sample, 53.3% were female; 60.6% were non-white; and 30.2% were first-generation students. Further, 77.1% of students reported that neither parent was an engineer. As such, this sample accurately reflects the target population our program aims to serve.

Results

Descriptive statistics revealed that the sample reported awareness, interest, enjoyment, opinion formation, and understanding of engineering that centers on the median of the scale (range = 8-27, M = 15.55, SD = 4.47). This finding suggests that high school students in the current sample have average to low understanding of engineering as a potential career field. Descriptive statistics also revealed that the sample reported awareness, interest, enjoyment, opinion formation, and understanding of engineers that again centers on the median of the scale (range = 14-22, M = 18.18, SD = 1.60). This finding suggests that high school students in the current sample have average to low understanding of engineers. Finally, descriptive statistics revealed that the sample reported engineering identities that center on the median of the scale (range = 24-51, M = 36.39, SD = 4.64). This finding suggests that high school students in the current sample have average engineering identities.

These findings are unsurprising, given the lack of STEM opportunities in traditional public school curricula; further, high school students are rarely provided with engineering-specific opportunities and educational experiences. Moreover, that our participants are lower in their awareness and understanding of engineering as a potential career field is what makes them the target population for pre-college engineering programming. This logic also applies to the finding that our sample yielded average engineering identities. Because the questionnaire was administered via the application process for the program, these data are baseline. We hypothesize that after one year of participation in the program, students' awareness and understanding of engineering as a potential career field, and of engineers, will significantly increase. We also hypothesize that program participation will significantly increase students' identities as engineers. Post-program data collection will allow us to examine these hypothesized increases, and will serve as a proxy measure to understanding the efficacy of our program. If our program showcases these increases, we can inform our current understanding of program logistics, as well as continue to make data-driven decisions about programming and marketing.

Inferential statistics were conducted to examine differences in scores on the *What is Engineering* and *Engineering Identity* measures, by gender, ethnicity, and first-generation status. Independent samples t-tests revealed no gender differences in describing engineering or describing engineers; however, significant gender differences in *Engineering Identity* did emerge, $t(207) = -2.16$, $p = .032$, $F = 3.16$. These data suggest that males scored significantly higher on our *Engineering Identity* measure compared to females. This finding is of little surprise, given extant research devoted to gender differences in STEM attitudes and behaviors, which consistently showcases that men have more developed identities as STEM professionals than women [27]. Because our program aims to address the gender gap in engineering by increasing female participation, we hope to bridge this gap by increasing female students' identities as engineers via Saturday workshops and events such as Evening with an Engineer. Independent samples t-tests revealed no significant ethnic differences in *What is Engineering*, nor in *Engineering Identity*, scores. This suggests that regardless of their reported ethnicity, students in the current sample have similar awareness and understanding of engineering as a potential career field, and have similarly developed identities as future engineers.

Finally, a one-way analysis of variance revealed significant differences in scores on the *What is Engineering* questionnaire, based on students' first-generation status. First-generation students scored significantly lower in *Describe Engineering*, $F(2, 176) = 4.03$, $p = .020$, compared to students who reported one or both parents earned a four-year degree. Additionally, first-generation students scored significantly lower in *Describe Engineers*, $F(2, 176) = 3.06$, $p = .049$; however, these data reflect marginal significance. As first generation students tend to have fewer engineering influences in their immediate family, explaining their tendency to select "neutral" as a response, it is important to provide them with opportunities to explore and learn more about how engineers impact society directly from engineers to understand from engineering students how they aspire to make an impact on society.

Future Directions

The measures of whether participants evince awareness and interest in engineering and the degree to which they develop engineering identity are key in assessing the influence of this extra-curricular program, *Young Engineers Shape the World* implemented by this NSF INCLUDES pilot alliance, *Engineers from Day One*. In order to fully assess whether participants have developed personal and social relevance, qualitative data analysis of an open ended-narrative response will be conducted to help confirm and augment results of quantitative data collection efforts. Further, both the *What is Engineering* questionnaire and the *Engineering Identity* survey will be administered at the end of the academic year, to test for significant increases as a result of program participation. Thus, via this NSF INCLUDES *Engineers from Day One* project, Arizona State University's Ira A. Fulton Schools of Engineering aims to demonstrate the significance of implementing deliberately designed learning experiences where participants' awareness and interest in engineering can be changed through the following key elements: (i) collaboration with peers; (ii) first-hand interaction with undergraduate engineering students and professional engineers from industry; (iii) activities to explore the social relevance of engineering embedded in the learning experiences.

If the results of pre-post comparison of data indicate that participants' demonstrated increased awareness and interest in engineering then, we anticipate that this interest will lead them to envisioning their future possible selves as engineers, which in turn will lead them to making informed choices about entering engineering as they make decisions by forming opinions about engineering (and thereby understand the personal and social relevance of engineering). We will follow participants to collect data about their college application and admissions process to measure admission and enrollment in engineering (or other STEM) undergraduate degree programs or 2-year associates degree programs. Our aim is to enhance entry into engineering for those traditionally under-represented in engineering and thereby broaden participation [28, 29] for first-generation students, women, under-represented ethnic minorities, and those with socio-economic need. Our overall goal is to assess whether our year-long extra-curricular program enhances high school students' interests in engineering and has any statistically significant results that could lead to entry into engineering 2- or 4-year degree programs.

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